

**Exhibit A:**  
**Knife-Edge Diffraction Analysis for 28 GHz**

(Erratum to June 1, 2016 filing with missing pages)

## Analysis of Diffraction Loss on the 5G-to-FSS-Satellite Path at 28 GHz

The analysis in this appendix was performed based on the assumptions discussed between SIA and Joint Filers.

Buildings can be major obstructions in the LOS path between terrestrial 5G systems deployed in urban and dense urban environments and FSS satellite receivers, leading to potentially significant diffraction loss that should be considered in the analysis of interference from 5G systems into FSS satellite receivers.

Relevant parts of the diffraction model are described in following paragraphs.

The solution to diffraction on the edge of an object is given using Fresnel integrals (equations 6 & 7 in [1]):

$$F_c(v) = \int_0^v \exp\left(j \frac{\pi s^2}{2}\right) ds = C(v) + jS(v), \quad (1)$$

where  $j$  is complex operator,  $C(v)$  and  $S(v)$  are Fresnel sine and cosine respectively:

$$C(v) = \int_0^v \cos\left(\frac{\pi s^2}{2}\right) ds, \quad (2)$$

$$S(v) = \int_0^v \sin\left(\frac{\pi s^2}{2}\right) ds, \quad (3)$$

where  $v$  is a geometrical parameter defined in equation 4 below.

Recommendation ITU-R P.526-13 [1] describes complex model for numerical integration (equation 8 in [1]) for positive values of  $v$ , but having tools such as Matlab allows effortless high-precision direct numerical integration of Fresnel equation. A standard, global adaptive quadrature method was used to compute integrals up to  $10^{-15}$  tolerance, which is close enough to machine error.

The single knife-edge obstacle case is described in [1] chapter 4.1, equations 28 & 30:

$$v = \text{sign}(\theta) \sqrt{\frac{2 h \theta}{\lambda}}, \quad (4)$$

$$J(v) = -20 \log \left( \frac{\sqrt{[1 - C(v) - S(v)]^2 + [C(v) - S(v)]^2}}{2} \right), \quad (5)$$

where  $\lambda$  is a wavelength,  $h$  is a height of the obstructing object,  $\theta$  is diffraction angle (both  $h$  and  $\theta$  are positive in NLOS case – see simulation world/geometry in the next chapter).

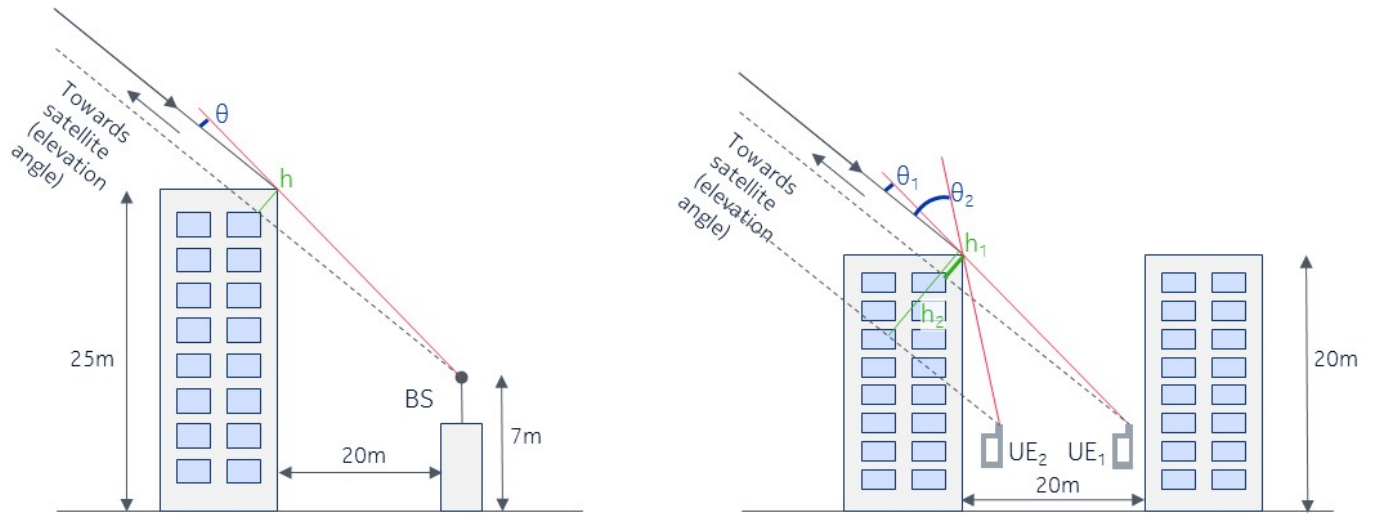
Again, approximate solutions were not considered due to more than enough computing power.

$J$  was multiplied by -1, which yields diffraction gain instead of loss. It also makes final results more intuitive, as object shadow is directly seen. Assumed frequency: 28 GHz.

## Simulation world/geometry

Even compared to sizes of large cities, satellites can be considered point objects at infinity. At any point in time, azimuth and elevation towards specific satellite is constant across large areas.

Simulation results in next section are based on simulation world/geometry depicted in Figure 1.



*Figure 1: Simulation worlds/geometries for BS and UE cases*

Geometry used to obtain the plots in Figure 2a and Figure 2b (results for BS case) is as follows:

- Building height 25m,
- Building distance 20m,
- BS antenna height 7m.

Geometry used to obtain the results for UE cases is as follows:

- Building height 20m,
- Building distance 20m,
- UE antenna height 1.5m.

Wherever distance to the building is defined, it applies to distance between diffracting edge wall and antenna. The used value of nominal distance between the buildings (20m) comes from Recommendation ITU-R P.452-16 [2] for urban/dense urban environment. Building heights were chosen based on statistical data shared by United States Census Bureau.

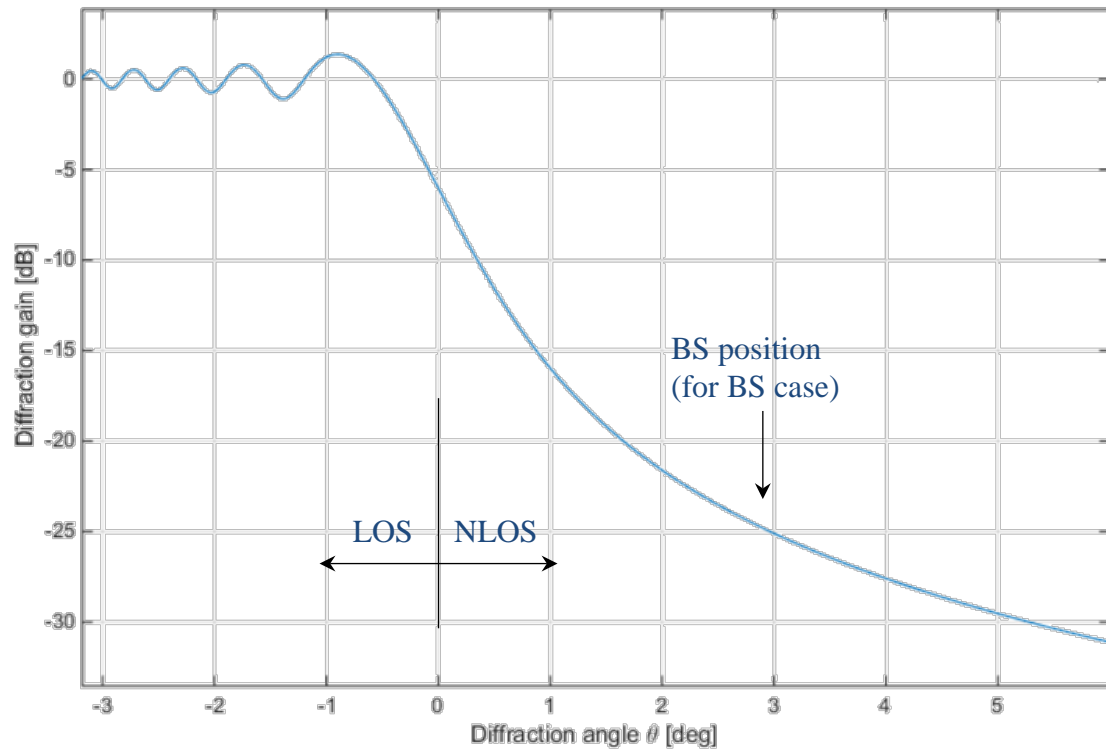


Figure 2a: Diffraction gain as a function of diffraction angle for BS case (low  $\theta$  values)

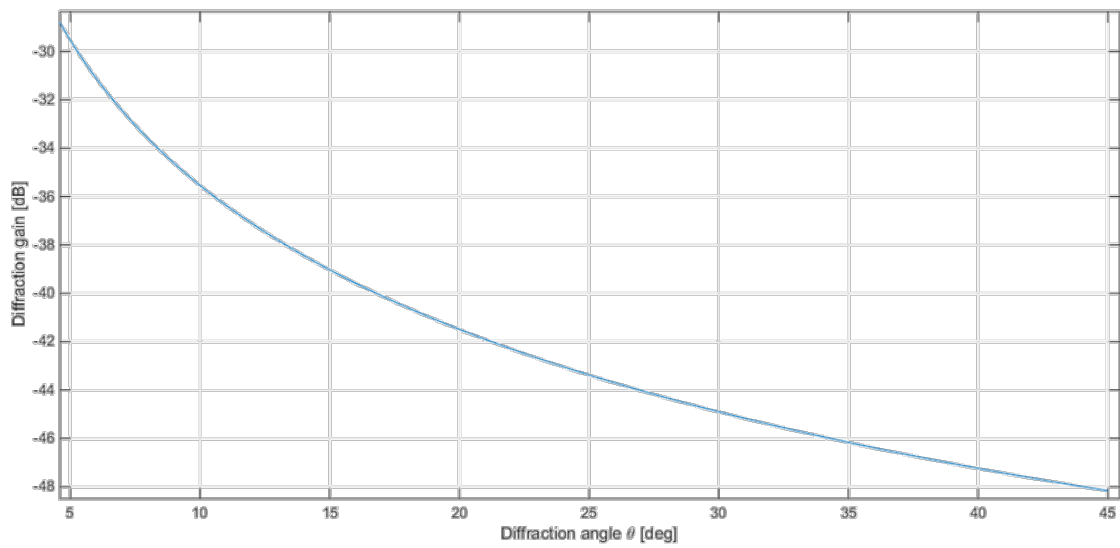


Figure 1b: Diffraction gain as a function of diffraction angle for BS case (high  $\theta$  values)

## Results

Corresponding diffraction gain shown in Figure 2a and Figure 2b are applicable to BS scenario case only, due to different geometry and resulting different  $v$  values than for UE cases.

Several elevation angles have been used in this analysis, i.e.  $5^\circ$ ,  $15^\circ$ ,  $30^\circ$ , as discussed with SIA. One additional elevation angle of  $39.06^\circ$  was also considered.

In the table below, values of **diffraction loss** at 28 GHz in few specific cases of interferers (5G BSs and UEs positions) and satellite elevation angle are presented.

*Table 1: Diffraction loss (J) for BS and UE cases*

Case	Satellite at $5^\circ$	Satellite at $15^\circ$	Satellite at $30^\circ$	Satellite at $39.06^\circ$
<b>BS case</b> - Building height 25m - Building spacing 20m - BS height 7m	$\theta=37^\circ$ $h=19.26\text{m}$ $v=48.2$ <b><math>J=46.6\text{dB}</math></b>	$\theta=27^\circ$ $h=14.5\text{m}$ $v=35.8$ <b><math>J=44\text{dB}</math></b>	$\theta=12^\circ$ $h=6.65\text{m}$ $v=16.1$ <b><math>J=37.1\text{dB}</math></b>	$\theta=2.93^\circ$ $h=1.635\text{m}$ $v=3.95$ <b><math>J=24.9\text{dB}</math></b>
<b>UE<sub>1</sub> case</b> - Building height 20m - Building distance 20m - UE height 1.5m	$\theta=37.8^\circ$ $h=17.3\text{m}$ $v=46.2$ <b><math>J=46.24\text{dB}</math></b>	$\theta=27.8^\circ$ $h=13.2\text{m}$ $v=34.5$ <b><math>J=43.7\text{dB}</math></b>	$\theta=12.8^\circ$ $h=6.25\text{m}$ $v=16.1$ <b><math>J=37.1\text{dB}</math></b>	$\theta=3.71^\circ$ $h=1.83\text{m}$ $v=4.7$ <b><math>J=26.4\text{dB}</math></b>
<b>UE<sub>2</sub> case</b> - Building height 20m - Building distance 2m - UE height 1.5m	$\theta=78.8^\circ$ $h=19.7\text{m}$ $v=71.2$ <b><math>J=50\text{dB}</math></b>	$\theta=68.8^\circ$ $h=18.7\text{m}$ $v=64.9$ <b><math>J=49.2\text{dB}</math></b>	$\theta=53.8^\circ$ $h=16.2\text{m}$ $v=53.4$ <b><math>J=47.5\text{dB}</math></b>	$\theta=44.8^\circ$ $h=14.16\text{m}$ $v=45.45$ <b><math>J=46.1\text{dB}</math></b>

## Conclusion

Typical diffraction loss in these cases is in range of 40-50 dB. Lowest attenuation cases (approximately 25 dB) are quite extreme, approaching LOS as noted by the diffraction angle values in these cases. In a previous filing<sup>14</sup>, the Joint Filers assumed an additional attenuation of only 20dB, which is 20-30 dB lower than the 40-50dB attenuation values derived in this analysis. Considering an additional 20-30dB

<sup>14</sup> See Letter from the Joint Filers to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.* (filed May 6, 2015) (“*May 6 Joint Letter*”) at Attachment 1, “FSS and UMFU Coexistence Simulations,” Nokia (May 6, 2016) (“*Nokia Simulation*”).

attenuation due to diffraction would further reduce the potential of interference from 5G systems to FSS satellite receivers.

It is also noted that the analysis performed took into account diffraction only. No additional sources of losses or gain were taken into account, such as scatter, vegetation, antenna directional gain or reflections.

## **References**

- [1] ITU-R P.526-13, Propagation by diffraction
- [2] ITU-R P.452-16, Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz